0

National Defence / Défense nationale

CONDUCT OF NAVIGATION SYSTEMS SEA TRIAL 92-01 (U)

by

M. Vinnins

DEFENCE RESEARCH ESTABLISHMENT OTTAWA
TECHNICAL NOTE 93-8

Canada

March 1993
Ottawa

National Defence / Défense nationale

Accesion For	
NTIS CRA&I	X
DTIC TAB	☐
Unannounced	☐
Justification	
By	
Distribution /	
Availability Codes	
Dist	Avail and / or Special
A-1	

CONDUCT OF NAVIGATION SYSTEMS SEA TRIAL 92-01 (U)

by

M. Vinnins
Communications and Navigation Section
Electronics Division

DEFENCE RESEARCH ESTABLISHMENT OTTAWA
TECHNICAL NOTE 93-8

PCN
041LJ

March 1993
Ottawa

ABSTRACT

A sea trial was held 9-26 August 1992 on board CFAV Endeavour out of CFB Esquimalt to record data from various navigation sensors to support ongoing development of an experimental development model (XDM) of DIINS (Dual Inertial Integrated Navigation System) and to evaluate the performance of MINS (Marine Integrated Navigation System) and of an Ashtech 3DF GPS (Global Position System) receiver. This report describes the preparation, installation and conduct of this trial.

RESUME

Du 9 au 26 août 1992, nous avons effectué un essai en mer à bord du AVCF Endeavour, rattaché à la BFC Esquimalt, pour relever les données des différentes capteurs du DIINS (Double système intégré de navigation par inertie) dans le but de poursuivre la mise au point selon le modèle expérimental et d'évaluer la performance tant du Système intégré de navigation de la Marine (MINS) que du recépteur Ashtech 3DF GPS (système de positionnement global). Le présent rapport décrit la préparation, l'installation et la conduite de cet essai.

EXECUTIVE SUMMARY

A Dual Inertial Integrated Navigation System (DIINS) is being developed at the Defence Research Establishment Ottawa (DREO). DIINS will integrate two ship's inertial navigation systems (INS's) with Transit, Loran-C, Omega, GPS and speedlog and will incorporate sensor failure detection, isolation and reconfiguration (FDIR) techniques.

A sea trial to collect sensor data was held on CFAV Endeavour out of CFB Esquimalt from 9 to 26 August 1992. Sensors for DIINS included a Sperry MK-29 INS, a Litton LTN-90-100 inertial reference system (IRS). Sensors for MINS (Marine Integrated Navigation System) consisted of a Magnavox MX1105 Transmit/Omega/GPS receiver, an Internav LC-204 Loran-C receiver, and Ashtech XII GPS receiver along with ship's gyro and speedlog.

Sensor data was recorded and time referenced using a GPS clock. 'True' position data was provided from a STARFIX/Differential GPS reference system and an additional sensor, an Ashtech 3DF attitude determining GPS receiver, was also evaluated.

This report details the sensor data outputs and data acquisition systems employed and discusses sensor installation, the sea trial plan and the actual conduct of the trial.

TABLE OF CONTENTS

1. INTRODUCTION

1.1 NAVIGATION SENSORS

DIINS is the Dual Inertial Integrated Navigation System being developed at the Defence Research establishment Ottawa (DREO) under tasking from the Director Marine and Electrical Engineering (DMEE). DIINS is a next-generation development of the Marine Integrated Navigation System (MINS), previously developed at DREO and now installed fleet-wide within the Canadian maritime forces.

MINS optimally integrates gyrocompass, speedlog, Transit, Loran-C, Omega and GPS sensors employing a 17-state extended Kalman filter along with sensor error correction and failure detection techniques. Details on MINS are described in References [1], [2] and [3].

DIINS incorporates two Inertial Navigation Systems (INS's) along with most of the previous sensors employed in MINS in a new design incorporating sensor failure detection, isolation and reconfigureation (FDIR) techniques.(4)

This report describes a 'data-acquisition' sea trial employing the individual DIINS sensors, as well as MINS with its sensors, and an Ashtech 3DF GPS receiver. This trial was conducted during 9-26 August 1992 on board CFAV Endeavour out of CFB Esquimalt, B.C. The sea trail was conducted off the west coast of Vancouver Island and an independent reference system was used as truth data. The area of operations was approximately between latitudes 48°N and 51°N and within 200 km of the west coast of Vancouver Island. The report is intended as a reference for future trials and, as such, contains numerous tables detailing options available for data recording.

The MINS sensor suite used for the trial consisted of:

a. Magnavox MX1105 receiver - Omega, single-channel Transit, (2-channel GPS)

b. Internav LC-204 receiver - single-chain Loran-C

c. Sperry MK-23 Mod C-3 - ship's gyrocompass

d. Sperry SRD-331 - Doppler speed log

e. Ashtech XII receiver - 12 channel, C/A code GPS

For DIINS we also included:

f. Sperry MK-29 Mod 3 - Inertial Navigation System

g. LTN-90 - Inertial Navigation System

All equipment except the gyrocompass and speedlog were supplied by DREO.

Note that only one Sperry MK-29 inertial navigation system was available for these trials. This limitation was overcome through the use of another sensor as described in the following section.

The second inertial sensor was acquired for use during this trial; a Litton LTN-90-100 Ring Laser Gyro (RLG) Inertial Reference System (IRS). Although designed for use in airborne applications, recent interest has been shown in the use of lower-cost (as compared to a full ship's inertial system such as the Sperry MK-29) inertial sensors integrated with GPS in some applications. The LTN-90 system was, therefore, included to permit evaluation for such applications in addition to being the second DIINS inertial system.

Additional interest exists as well in the area of attitude determination employing the GPS. Recent developments in phase tracking, multi-channel receivers have resulted in several commercial attitude-determining GPS receivers, in particular, the Ashtech 3DF receiver. EDO Canada of Calgary was contracted to install and operate an Ashtech 3DF attitude determining GPS system during the trial. The receiver employed four antennas and further details on installation, calibration and data recording are provided later in this report.

1.2 REFERENCE SYSTEM

McElhanney Associates of St. Johns, Newfoundland, were contracted to provide a position reference system for the trial. The selected system was STARFIX and Differential GPS (DGPS). STARFIX is a privately owned and operated satellite-based positioning system employing four geostationary communications satellites. Two tracking stations transmit signals to the satellites which respond by sending signals back to earth; the measured phase differences provide pseudo-ranges which are then relayed to users through communication links on the satellites.

As a backup, DGPS was employed using a base station at Everett, Washington, as a reference. The GPS corrections were relayed through the STARFIX satellites on a continuous basis providing real-time DGPS.

Quoted accuracies for the reference system were:

a. 5-10 metres, 24 hours per day for STARFIX;

b. 5-7 metres (dependent on PDOP) for DGPS.

Recording of the reference data is described in another section of this report.

2. DATA ACQUISITION

2.1 TIME REFERENCE

Due to the variety of sensors, the extremely large quantities of data to be recorded, and the practical aspects of locating the sensors on board the vessel, it was decided that several data recording systems would be used during the sea trial. In order to relate events between the systems, all were referenced to a common clock; GPS time.

For this purpose, a Trak Systems GPS Station Clock, Model 8810, was procured. This unit contains a six-channel continuous tracking receiver and a precision time signal generator which allows simultaneous tracking of up to six GPS satellites and displays antenna position, UTC time and either GPS or local time. Time and frequency signal outputs are synchronized to within 100 nanoseconds of GPS/UTC time as received from the satellites.

An internal crystal oscillator is used when no satellites are being tracked and no external reference frequency is available. Time output drift with this local oscillator is one microsecond per hour.

The data output from the station clock is available in numerous formats. For our purposes an IRIG-B time code format was used.

To interface to several PCs used for data logging, IRIG-B Synchronized Generator Clock Cards (PC-SG) were used. These cards consist of a synchronized generator with a crystal time base that phase-locks to and decodes IRIG-B time code. The card outputs time on demand so that the PCs could record the exact times when they receive data. For these trials, all data was referenced to GPS time.

In this manner, all data could be time referenced for post-trial processing.

2.2 SENSOR DATA RECORDING

The various components were installed in three separate laboratories on the ship:

- Sperry MK-29 in the 'Wet Lab'
- LTN-90 in the 'Dry Lab'
- MINS in the 'Computer Lab'.
- Ashtech 3DF in the 'Computer Lab'

Due to the physical distance between these sensors, three separate data recording systems were employed.

2.2.1 **Sperry MK-29**

Data from the MK-29 INS is available on an RS-232 serial digital interface [5][6]. The MK-29 sends 33-byte messages every 160 msec (a rate of 6.25 Hz). Each message block includes 15 bytes of data reflecting parameters updated at a rate greater than 6.25 Hz, a 16-byte block of data updated at 0.78125 Hz, a checksum byte and the inverse of the checksum byte. See Table 1.

Variable	Byte Number	Description
Vi	1, 2	North velocity
Vj	3, 4	East velocity
Vk	5, 6	Vertical velocity (optional)
Heading	7, 8	Heading
Roll	9, 10	Roll (optional)
Pitch	11, 12	Pitch (optional)
Status	13	Mx time matrix, command status
ΔT	14	0-24 (40 ms time)
Code	15	0 = no date, 1-8 = Block no.
Block	16-31	8 16-bit words
cksm	32	sum of bytes 1-31
cksm	33	logical NOT of byte 32

TABLE 1. MK-29 Digital Output Format

A set of eight consecutive data blocks (numbered 1 to 8) makes up a complete 1.28 second message.

The data is output in bursts, evenly spaced, each containing a single message. Encoded within each message at byte 15 is the block label identifying which of the 8 blocks is contained in this message. A list of the data contained in the messages, including that in each block is shown in Table 2.

Word(s)	Variable(s)
	Block 1
1, 2	Day/time
3, 4	Status
5, 6	Latitude
7, 8	Longitude
	Block 2
1	V_t, ships total velocity
2	CMG, ship's course made good
3	V_{cn}, Northerly ocean current
4	V_{ce}, Easterly ocean current
5	1-sigma estimate of Latitude error
6	1-sigma estimate of Longitude error
7	Δhdg, SKOR Heading correction
	Block 3
1	Δlat, SKOR Latitude correction
2	Δlon, SKOR Longitude correction
3, 4	Time of last accepted fix
5, 6	Fix lat, last fix Latitude
7, 8	Fix lon, last fix Longitude
	Block 4
1	X gyro bias correction (note 1)
2	X gyro random drift correction (note 1)
3	Y gyro bias correction (note 1)
4	Y gyro random drift correction (note 1)
5	Z gyro bias correction (note 1)
6	Z gyro random drift correction (note 1)
7	Z gyro ramp correction (note 1)
8	V_{ref}, Reference velocity
	Block 5
1, 2	Time of last Magnavox (Mx) fix (note 2)
3, 4	Mx fix Latitude (note 2)
5, 6	Mx fix Longitude (note 2)
7	1-sigma estimate of Mx Lat error (note 2)
8	1-sigma estimate of Mx Lon error (note 2)
	Block 6
1, 2	Mx satellite no. and quality flags (note 2)
3	Mx Omega stations and fix quality (note 3)
4	<spare>
5, 6	dV_i, Northerly velocity correction
7, 8	dV_j, Easterly velocity correction
	Block 7
1	ABX_i, Northerly accelerometer bias correction
2	ABX_j, Easterly accelerometer bias correction
3, 4	D_i, Northerly case-fixed drift correction
5, 6	D_j, Easterly case-fixed drift correction
7, 8	<spare>
	Block 8 <spare>

TABLE 2. Block Data Formatting

A DOS-based data logging program 'LOGMK29.EXE' was written for use on a Toshiba model 5100E laptop computer with a 200 Mb hard disk drive [7]. The program automatically aligns to the incoming MK-29 data stream, stores data into binary files and displays portions of the data to the display screen for monitoring purposes. The program also employs an IRIG-B PC-SG interface card connected to the GPS clock to time tag the data.

The program aligns itself to the 33-byte output message format and then traps message #1 and begins recording each of the data messages from that point on. Each message gets a GPS time stamp which is accurate to better than 10 msec for the message transfer itself. The latency of the data contained within each message relative to the time of transfer of the message is given in the Sperry documentation[5].

A standard filenaming convention has been estalished for the data logging programs. In this case the file name begins with an "S" denoting data from the Sperry MK-29 MOD 3. The file name extension is hardcoded "R92" for raw data collected in the year 1992. The entire file name is as shown below:

SDDDHHMM.R92

where DDD is the Julian day of the year;
HH is hour of file creation;
MM is the minute of file creation.

When a data file is opened, the software queries the clock for the present time and uses this data in naming the file. The data logging system is set up to store approximately 1 hour's worth of data in a single file, then to close the file and open another without user intervention. This essentially turn-key system will run until the user commands it to stop or disk space is no longer available. An hour of data requires slightly less than 1 Mbyte of storage space, or approximately 24 Mbytes per day.

The data capture and alignment utility constantly checks alignment for transfer errors at the byte level. If a checksum or alignment error is detected the program informs the user and data logging continues after re-alignment.

Data logging concludes upon user command. This closes the open data logging file after reception of the present message block.

Because of the extensive volume of data being recorded, the logged data is stored in binary format. Each recorded message is preceded by a two-character delimiter and the GPS time from the PC-SG IRIG-B card. The entire 33-byte message

from the MK-29 is then recorded. This is repeated until data collection ends. Note that the GPS time is taken at the reception of the first byte of the message to reduce latency. The data file format is illustrated in Table 3.

Byte #	Description	Notes
1-2	2 Character Delimiter	"$$"
3-4	Seconds	Unsigned Int (Intel Format)
5-6	Minutes	Unsigned Int (Intel Format)
7-8	Hours	Unsigned Int (Intel Format)
9-10	Days	Unsigned Int (Intel Format)
11-43	MK-29 Message	See Sperry Documents

TABLE 3. MK-29 Data File Format

2.2.2 LTN-90

Data from the LTN-90 IRS is available in ARINC-429 format. (Note that this is an airborne application platform.) ARINC-429 is a standard high speed, digital data bus providing 'labelled' binary data as listed in Table 4. It should be noted that the update rates for output parameters vary from 1 to 64 Hz. (These data rates are typical in airborne applications.) Each ARINC data sample is 32 bits.

Label	Parameter	Update Rate (Hz)	Numeric Range	Units	Sig Bits	Resolution	Positive Sense	Label
310	Pres POS-LAT.	8	± 180	Deg	20	0.000172°	North from zero deg	310
311	Pres POS-LONG	8	± 180	Deg	20	0.000172°	East from zero deg	310
312	Ground Speed	16	4096	Knots	15	0.125 KTS	Always positive	312
313	Track Angle True	32	± 180	Deg	15	0.005493°	CW from north	313
314	True Heading	32	± 180	Deg	15	0.005493°	CW from north	314
315	Wind Speed	16	0.256	Knots	15	0.007813 Kts	Always positive	315
316	Wind Direct True	16	± 180	Deg	15	0.005493°	CW from North	316
317	Track Angle Mag	32	± 180	Deg	15	0.005493°	CW from North	317
320	Mag Heading	32	± 180	Deg	15	0.005493°	CW from North	320
321	Drift Angle	32	± 180	Deg	15	0.005493°	Right	321
322	Flight Path Angle	32	± 180	Deg	15	0.005493°	Up	322
323	Flight Path Accel	64	± 4	G	15	0.000122 G	Forward	323
324	Pitch Angle	64	± 180	Deg	15	0.005493°	Up	324
325	Roll Angle	64	± 180	Deg	15	0.005493°	Right Wing Down	325
326	Body Pitch Rate	64	± 128	Deg/sec	15	0.003906°/sec	Up	326
327	Body Roll Rate	64	± 128	Deg/sec	15	0.003906°/sec	Right Wing Down	327
330	Body Yaw Rate	64	± 128	Dec/sec	15	0.003906°/sec	Nose Right	330
331	Body Longit Accel	64	± 4	G	15	0.000122 G	Forward	331
332	Body Lateral Accel	64	± 4	G	15	0.000122 G	Right	332
333	Body Normal Accel	64	± 4	G	15	0.000122 G	Up	333
334	Platform Heading	16	± 180	Deg	15	0.005493°	CW from Zero Deg	334
335	Track Angle Rate	64	± 32	Deg/sec	15	0.000977°/sec	CW	335
336	Pitch Att Rate	64	± 128	Deg/sec	15	0.003906°/sec	Up	336
337	Roll Att Rate	64	± 128	Deg/sec	15	0.003906°/sec	Right Wing Down	337
360	Potential Vert Speed	32	±32,768	ft/min	15	1.00 ft/min	Up	360
361	Inertial Altitude	32	±131,072	ft	20	0.125 Ft	Up	361
362	Along Trk Horiz Accel	64	± 4	G	15	0.000122 G	Forward	362
363	Cross Trk Horiz Accel	64	± 4	G	15	0.000122 G	Right	363
364	Vertical Accel	64	± 4	G	15	0.000122 G	Up	364
365	Inertial Vert Speed	32	±32,768	ft/min	15	1.00 ft/min	Up	365
366	N-S Velocity	16	± 4,096	Knots	15	0.125 Kts	North	366
367	E-W Velocity	16	± 4,096	Knots	15	0.125 Kts	East	367

TABLE 4. Digital Output Data Characteristics[8]

Data Logging was, again, performed on a PC; in this case a KMS Advanced Products Model RMC-3000 ruggedized computer running a DOS operating system and having a 100 Mb hard drive.

To interface the ARINC-429 data, a PC interface card, the Excalibur DAS-429-PC, was employed. This interface is a multi-channel card containing 1 transmit and 2 receive channels.[10]

The data logging system [9] provides a driver for the card at receive channel 0. The software initializes this channel and logs specific data labels to hard disk at 0.5 second intervals. A GPS time stamp is also recorded with each data sample.

For our purposes, only 16 data labels were selected to be logged. These are listed in Table 5.

At present the data is stored in a buffer according to its label. With each update, the particular label's data is overwritten with the new value. The entire 32-bit ARINC word is stored along with a 32-bit time tag from a free running 10 MHz clock on the DAS-429-PC card. A 16-bit error count and a 16-bit status word conclude the information for one label. Thus, each label stored requires twelve 8-bit bytes of disk space.

Label [8]	Description
310	Present Position - Latitude
311	Present Position - Longitude
366	N-S Velocity
367	E-W Velocity
325	Roll Angle
324	Pitch Angle
314	True Heading
327	Body Roll RAte
326	Body Pitch Rate
330	Body Yaw Rate
331	Body Longitudinal Acceleration
332	Body Lateral Acceleration
333	Body Normal Acceleration
334	Platform Heading
361	Altitude (Inertial)
365	Inertial Vertical Velocity (EFI)

TABLE 5. Logged ARINC-429 Labels

The 12 bytes of each label are transferred to disk at each 0.5 sec sample period along with a GPS time stamp. At each sample period, the time stamp is frozen in a buffer on the IRIG-B card and then the ARINC data is logged through the ARINC interface card. This entire set of data is then dumped to disk. This limits the latency to the update period of the data on the ARINC bus. (For most of the labels selected, this is less than 20 msec.)

Total data being logged consists of (16 labels of 32-bit data) 192 bytes of ARINC data per sample in addition to 8 bytes of GPS time and 2 bytes for a redundant delimiter for a total of 202 bytes at a 2 Hz rate. This results in 1.454 Mbytes of data per hour or 35 Mbytes per day.

The data files conform to a standard naming convention determined prior to the trials. In the case of the LTN-90-100 data, the file names begin with an L and have the extension "R92" for raw data from 1992. The names are as depicted below:

LDDDHHMM.R92

where DDD is the GPS Julain Day;
HH is the GPS hour of file creation;
MM is the GPS minute of file creation.

The data logging system was set up to store approximately 1.4 Mbytes of data in each file to aid in backing up the data while on the ship. With 16 labels this corresponds to about 1 hour of data. No user intervention is required until testing has concluded or the disk is full. It is the user's responsibility to ensure enough disk space exists at all times.

The logged data is stored in binary format. A data file record consists of a two-character delimiter followed by an 8-byte GPS time stamp. Each ARINC label (12 bytes) then follows as shown in Table 6.

Byte #	Desription	Notes
1-2	2-Character Delimiter	"$$"
3-4	Seconds	Unsigned Int (Intel Format)
5-6	Minutes	Unsigned Int (Intel Format)
7-8	Hours	Unsigned Int (Intel Format)
9-10	Days	Unsigned Int (Intel Format)
11-12	Data Word - Hi	‡
13-14	Data Word - Low	‡
15-16	Time Tag - Hi	Unsigned Int (Intel Format)
17-18	Time Tag - Low	Unsigned Int (Intel Format)
19-20	Error Count	Unsigned Int (Intel Format)
21-22	Status/Ctrl Word	‡

‡ Descriptions of the data words stored and the Status/Ctrl word is found in the Excalibur Systems DAS-429-PC User's Manual.

The format of bytes 11 through 22 are repeated for each label recorded, in this case 16 ending with byte #202 the Status/Ctrl Word for label 365[8].

TABLE 6. LTN-90 Data File Format

2.2.3 MINS

Data output is not ordinarily available from a standard MINS unit but an optional data logging capability has been added to the DREO MINS unit (software version '2.01 with DREO Datalogger') for system develop and test activities.

The MINS data was available on an RS-232 serial line at 2400 baud and included the following data at a 20 sec interval:

- MINS position (integrated solution)
- GPS position (from Ashtech XII)
- Deadreckoned position (from gyrocompass and speedlog)
- Transit position (deadreckoned between fixes)
- Omega position
- Loran-C position (deadreckoned when less than 2 TDs available)
- Time (referenced to GPS time)

No individual raw sensor data was available from this software version.

Since GPS time was available through the MINS data, no further time tagging was required.

For simplicity, MINS data was logged directly onto a Tracker Disc System data recorder on 3.5 inch floppy discs. Due to the smaller volume of data as compared to the MK-29 or the LTN-90, this system was quite adequate. A model 1520 dual-floppy recorder was used for the sea trial and data was recorded on one floppy and then switched to the second one automatically to prevent data loss. One 1.4 Mbyte floppy lasted 7.5 hours during the trial.

Default file names were assigned by the recorder as 'Z001', 'Z002', etc., and each floppy was subsequently labelled by the operator to prevent confusion.

2.2.4 ASHTECH 3DF

The Ashtech 3DF system was installed by Ashtech and EDO Canada representatives. Data was logged at a 1 Hz rate and files were downloaded to a PC at regular intervals during the trial. A 'log book' of the data files is shown in Table 7.

Data was recorded in binary format and included the GPS time, permitting time matching with all other sensor data during post-processing.

Day	GMT	Comment
230	19:00	System startup
	19:12	Set Altitude known to "N"
	19:37	Crane operating on quay caused interference
		Ship underway, leaving quay
	19:55	Smoothing switched to "ON"
	20:05	Set Altitude known to "Y" at 0 m
		Set Altitude known to "N"
	20:27	Smoothing switched to "OFF"
	21:40	Logging Computer locked-up, Rebooted computer
	22:09	Opened logging file "BTST1A92.230"
	22:13	Set MaxRMS value to 10mm
231	10:17	Closed logging file "BTST1A92.230"
	10:17	Opened logging file "BTST2A92.231"
	18:55	Closed logging file "BTST2A92.231"
	19:04	Opened logging file "BTST3A92.231"
232	18:55	Closed logging file "BTST3A92.231"
	19:30	Opened logging file "BTST4A92.232"
	22:55	Stopped logging to file "BTST4A92.232"
	23:01	Appended logging to file "BTST4A92.232"
233	19:05	Closed logging file "BTST4A92.232"
		Opened logging file "BTST5A92.233"
234	19:00	Closed logging file "BTST5A92.232"
		Opened logging file "BTST6A92.234"
235	18:56	Closed logging file "BTST6A92.232"
		Opened logging file "BTST7A92.235"
236	19:00	Closed logging file "BTST7A92.232"
		Opened logging file "BTST8A92.236"
237	16:20	Closed logging file "BTST8A92.236"
		Trial Ends

TABLE 7. Ashtech 3DF Data File Log

Data was logged using an Ashtech-developed software package called 'GPS Post-Processing Software' (GPPS)[11]. A data logging routine permits data to be recorded into three separate files:

B-file containing satellite measurement and position data;

E-file containing satellite ephemeris data; and

A-file containing attitude data in a binary form.

The attitude data file format is shown in Table 8.

	Bytes	Contents
	11	Header
	8	Heading in degrees
	8	Pitch in degrees
	8	Roll in degrees
	8	BRMS in metres
	8	MRMS in metres
	4	Seconds-of-Week in milliseconds
	1	Attitude reset flag
	1	Spare bit which is not used
	2	Checksum (sum of words from header to spare)
	1	Carriage return
	1	Line feed
Total bytes	61	

TABLE 8 Attitude Data File [12]

MRMS is the average double difference carrier phase residual. Typical values are 2-3 millimetres.

BRMS is the RMS error for the differences between calibrated baseline magnitudes and computed baseline magnitudes for the three vectors formed by Antenna 1 to the other three antennas (vectors 1-2, 1-3, and 1-4). Typical values are around 1-3 centimetres. This error will increase under high PDOP conditions.

The attitude reset flag actually indicates the type of attitude that is being output. A "0" indicates that the phased ambiguities have been solved and a precise carrier phase attitude has been computed. A "1" indicates that the phase ambiguities have not been solved and a codephase heading estimate is given - pitch and roll are set to exactly 0.

This data was later provided to DREO by EDO in ASCII file format for comparison with other sensors employed during the trial.

2.3 REFERENCE SYSTEM DATA RECORDING

McElhanney Associates provided the reference system and performed all data logging and post-processing before submitting time referenced position data to DREO.

The recorded sensor data is listed in Table 9.

GPS	STARFIX
Julian Day	Altitude
GPS Year	Spheroid
GPS Time	V_n
DOP	V_e
# of SVs	Master Sigma
Northing	Age of Data
Easting	Northing
Height	Easting

In addition, gyro heading and speed were recorded.

TABLE 9. Logged Reference Data

Data was recorded at 1-second intervals on a HP computer and a hard copy printout was provided at 5-second intervals. The data was post-processed by McElhanney Associates and provided to DREO in a 5-second interval format containing time, northing, easting, DGPS latitude and longitude and combined STARFIX/DGPS latitude and longitude. No further data was available.

3. SEA TRIAL

3.1 INSTALLATION OF SENSORS

CFAV Endeavour, shown in Figure 1, is a research-dedicated vessel operated by National Defence out of CFB Esquimalt, Victoria, B.C. The ship has three laboratories designated the 'Wet' lab (forward, main deck), the 'Dry' lab (aft, main deck) and the 'Computer' lab (hangar deck). Although all of the laboratories are quite large, ease of installation and convenience dictated that the sensors be distributed amongst all three laboratories. This was a dedicated DREO Navigation trial (MINS, DIINS, 3DF) and no other scientific groups accompanied us.

As the name DIINS implies, two inertial systems were required, the Sperry MK-29 in the (forward) Wet lab and the Litton LTN-90 in the (aft) Dry lab. Both systems required alignment with the ship's centreline and this involved extensive effort on the part of Ship Repair Unit, Pacific (SRU(P)) and the Naval Engineering Unit, Pacific (NEU(P)). Precise mounting/levelling plates were designed by NEU (P) for both systems and then fabricated and installed by SRU(P). Alignment to the ship's centreline was complicated by the fact that CFAV Endeavour does not have a permanent datum. The reference was, therefore, taken from ship's drawings wherein bulkheads and other major structures are referenced to the ship's keel. A survey crew established a reference datum by physically levelling the ship with large weights and using a generator mounting surface in the engine room as the level (vertical) reference. An electronic levelling system was used to transfer vertical reference (level) to each mounting plate.

The heading (azimuth) reference was established using the main forward-running bulkhead of the ship as the reference line since its orientation is known with respect to the keel. The MK-29 and LTN-90 mounting plates were both referenced to this line in fore/aft orientation and positioned (for practical purposes) 48" to starboard of this reference line.

The alignment procedure used for the MK-29 is contained in the system installation and user's manual, Chapter 8.[13]

The MK-29 was determined to be level to within ± 1 arc sec in pitch and < 1 arc sec in azimuth (with respect to the onboard datum).

The LTN-90 azimuth was within ± 15 arc sec (0.07 milliradians) of the MK-29 and the pitch was ± 4 arc sec and the roll ± 5 arc sec.

FIGURE 1

CFAV Endeavour

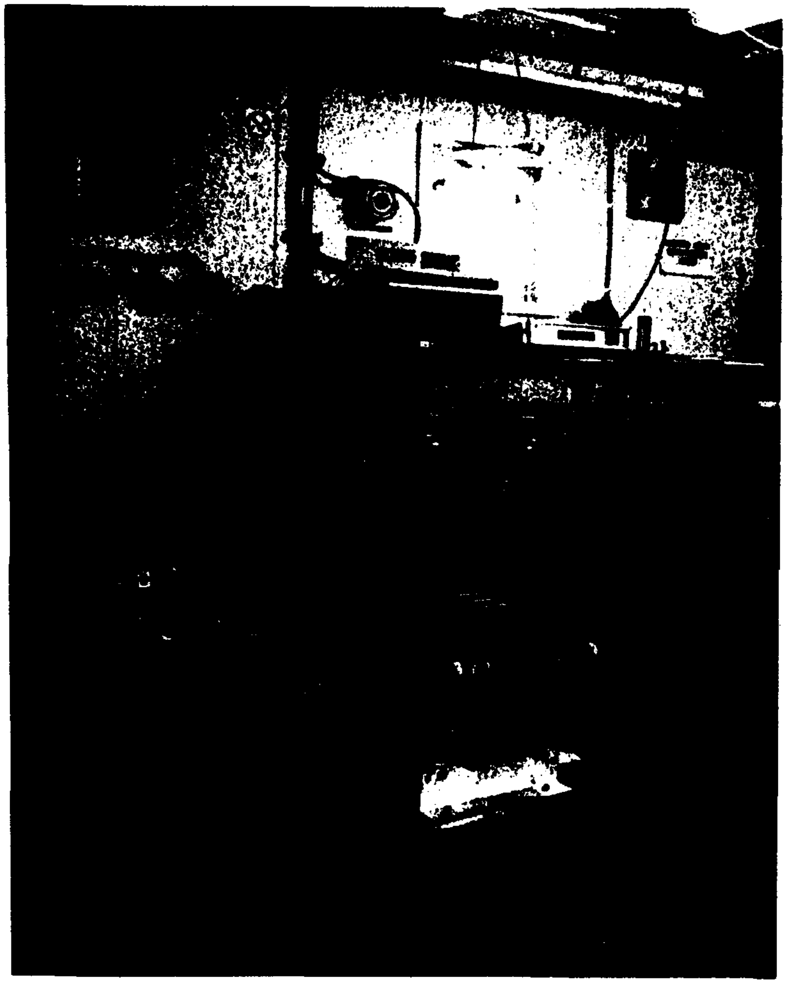


FIGURE 2

LTN-90 Installation

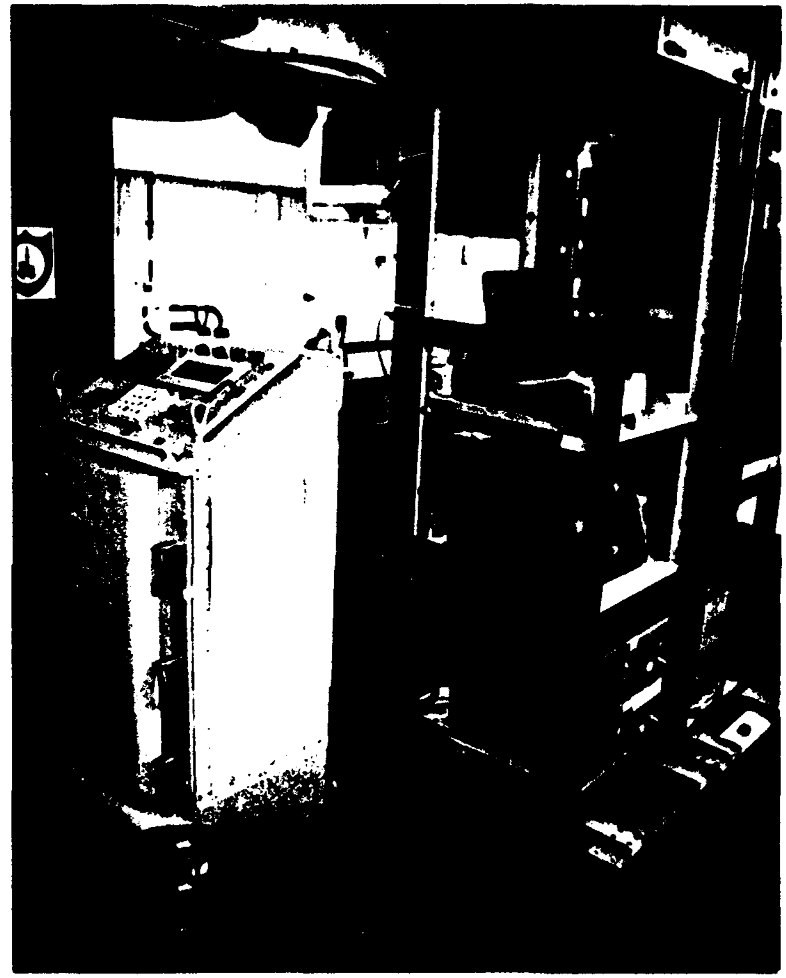


FIGURE 3

MK-29 Installation

Both inertial sensors were installed and initialized. The MK-29 was provided with ship's speedlog signals in synchro format. The LTN-90 was provided with no external aiding.

The GPS clock was installed in the Dry lab and timing signals provided to the LTN-90 and MK-29 recording systems. Photos of the installations are shown in Figures 2 and 3.

The MINS was installed in the Computer lab to minimize cable lengths to the antennas. A photo is shown in Figure 4.

The Ashtech 3DF system was also installed in the Computer lab. A diagram of all antenna locations is shown in Figure 5. Note the positioning of the four Ashtech 3DF antennas. Figure 6 demonstrates the heading offset of the 3DF attitude determination system with respect to actual ship's centre line. The 3DF system was calibrated for 48 hours at dockside to determine the reference attitude with respect to the ship. This is performed automatically by the receiver.

The McElhanney STARFIX/DGPS reference system was located in the Wet lab near the MK-29 system. This permitted simple comparison of position and nominal performance between the systems. The STARFIX antennas were mounted as high as possible on the superstructure to allow the best possible view to the horizon. A photo of antenna installations is shown in Figure 7. The STARFIX dish antenna is inside the large mushroom-shaped structure in the centre of the photo and is flanked by a Loran-C whip antenna (on hand-rail) and Transit/GPS (MX1105) on the left and Ashtech GPS on the right.

3.2 SEA TRIAL PLAN

A waypoint grid was selected covering a 40 mile by 60 mile area off the west coast of Vancouver Island. The area is shown in Figure 8 and a list of the waypoints is given in Table 10.

FIGURE 4

MINS Installation

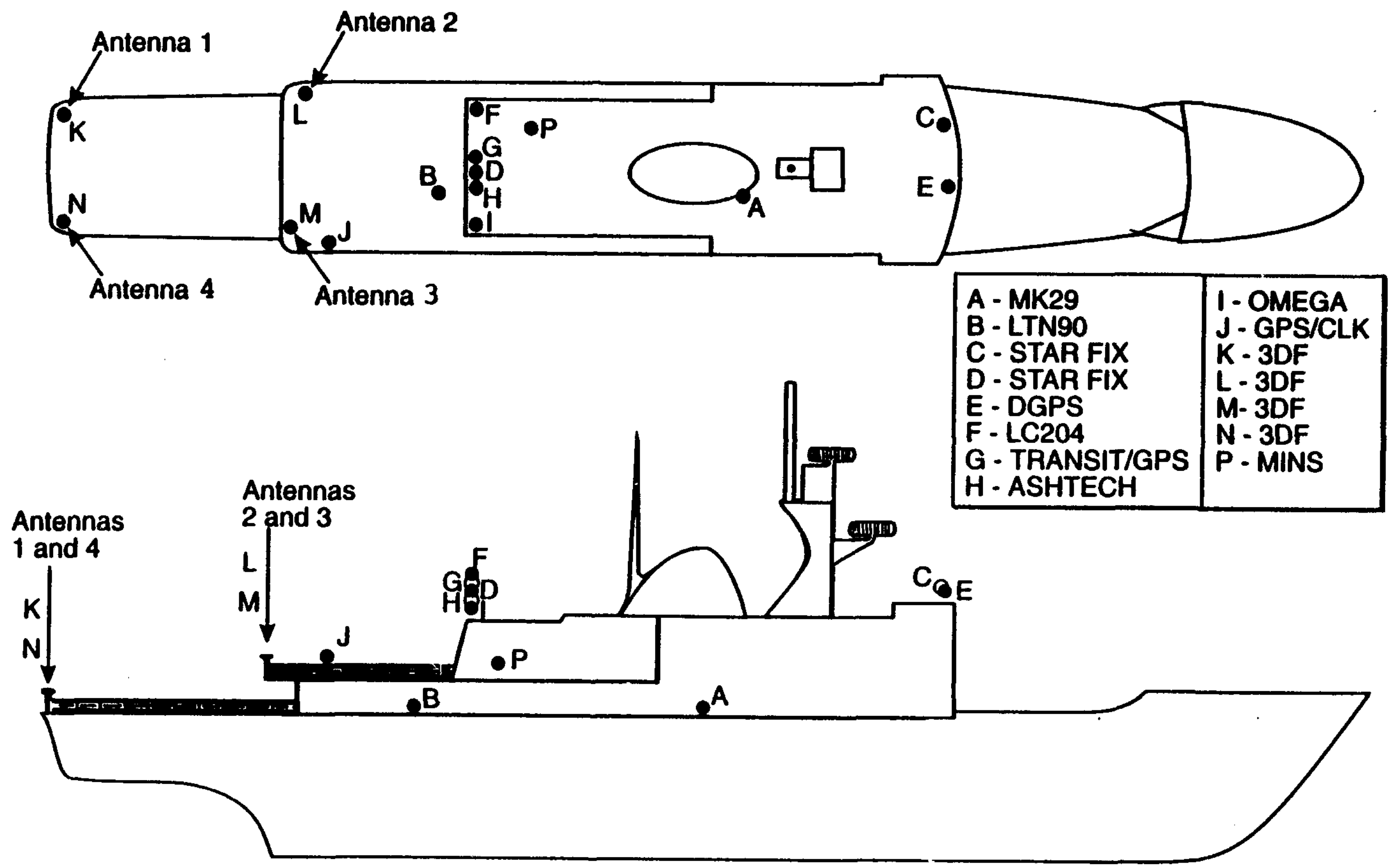
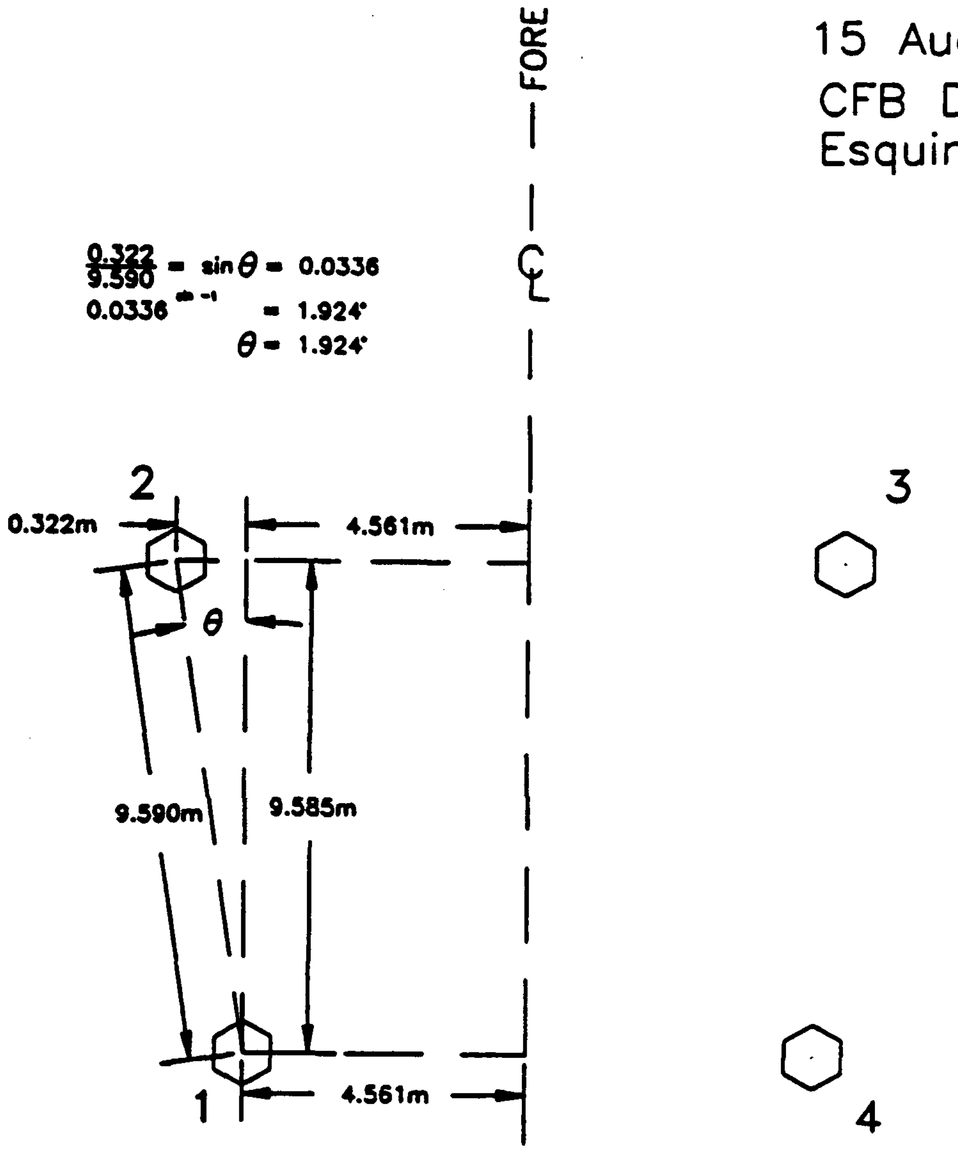


FIGURE 5

Approximate Antenna and INS Locations

Heading Offset Computation: CFAV Endeavour

15 Aug. 1992
CFB Dockyard
Esquimalt, B.C.



Measurements from ℄ to antennas 1 & 2 by hand tape.
Measurements from antenna 1 to antenna 2 by GPS survey.

Antennas 1 & 4 located on afterdeck taffrail.
Antennas 2 & 3 located on flightdeck taffrail.

FIGURE 6

Ashtech 3DF Heading Offset Computation

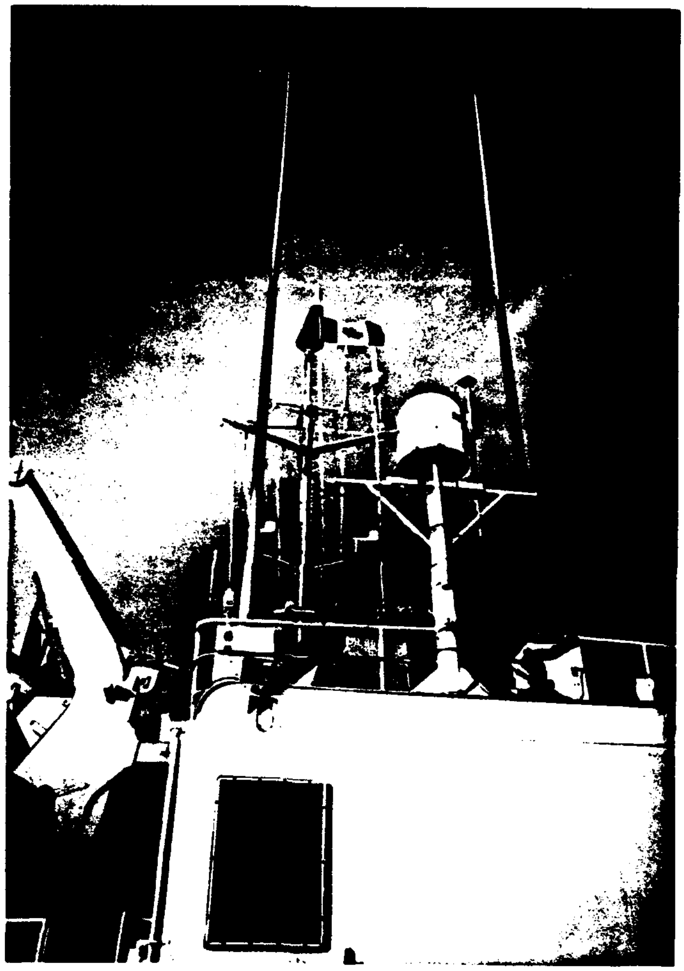


FIGURE 7

STARFIX, Loran, Transit, GPS Antenna Installations on Top of Hangar

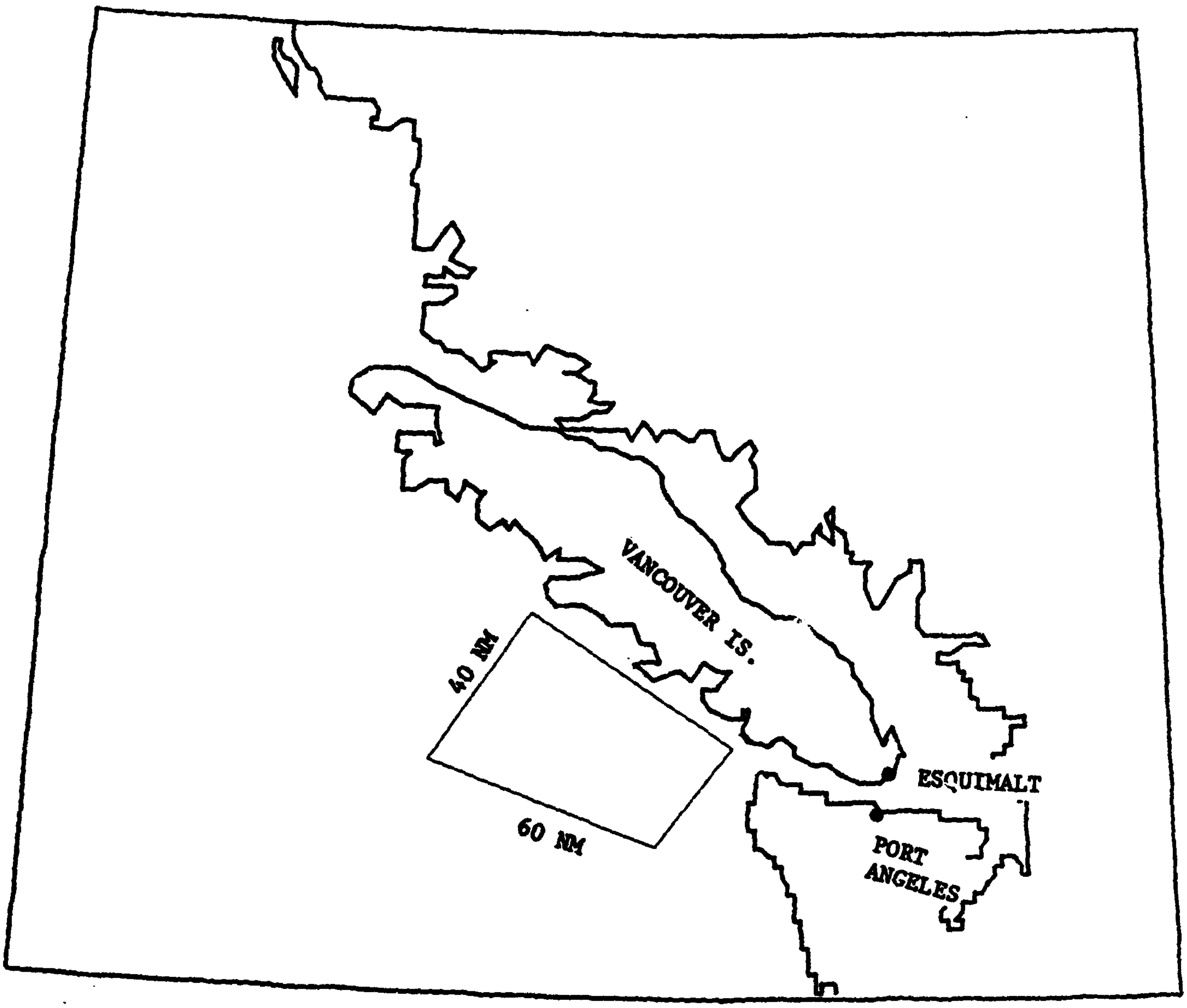


FIGURE 8

DIINS Trial 92-01 Operating Area

Designation	Latitude	Longitude
Alpha	48° 35′N	125° 10′W
Beta	48° 30′N	125° 10′W
Charlie	48° 25′N	125° 10′W
Delta	48° 25′N	125° 20′W
Echo	48° 30′N	125° 20′W
Foxtrot	48° 35′N	125° 20′W
Golf	48° 40′N	125° 20′W
Hotel	48° 45′N	125° 30′W
India	48° 40′N	125° 30′W
Juliette	48° 35′N	125° 30′W
Kilo	48° 30′N	125° 30′W
Lima	48° 25′N	125° 30′W
Mike	48° 25′N	125° 40′W
November	48° 30′N	125° 40′W
Oscar	48° 35′N	125° 40′W
Papa	48° 40′N	125° 40′W
Quebec	48° 45′N	125° 40′W
Romeo	48° 50′N	125° 40′W
Sierra	48° 55′N	125° 50′W
Tango	48° 50′N	125° 50′W
Uniform	48° 45′N	125° 50′W
Victor	48° 40′N	125° 50′W
Whiskey	48° 35′N	125° 50′W
X-Ray	48° 30′N	125° 50′W
Yankee	48° 25′N	125° 50′W
Zulu	48° 25′N	126° 00′W
AA	48° 30′N	126° 00′W
BB	48° 35′N	126° 00′W
CC	48° 40′N	126° 00′W
DD	48° 45′N	126° 00′W
EE	48° 50′N	126° 00′W
FF	48° 55′N	126° 00′W
GG	49° 00′N	126° 00′W
HH	49° 00′N	126° 05′W
II	48° 55′N	126° 05′W
JJ	48° 50′N	126° 05′W
KK	48° 45′N	126° 05′W
LL	48° 40′N	126° 05′W
MM	48° 35′N	126° 05′W
NN	48° 50′N	126° 10′W
OO	48° 55′N	126° 10′W
PP	48° 00′N	126° 10′W

TABLE 10. Waypoint Listing

The formal sea trial plan consisted of several manoeuvres.

3.2.1 Heading Sensitivity Test

Alpha
Bravo
Charlie
Delta
Lima
Mike
Yankee
Zulu
Alpha Alpha
Bravo Bravo
Charlie Charlie
Delta Delta
Echo Echo
Foxtrot Foxtrot
Golf Golf
Sierra
Romeo
Hotel
Golf
Alpha

This route was followed twice at approximately 8-10 knots.

3.2.2 Short Term Noise Test

Golf
Foxtrot
Echo
Kilo
November
Oscar
Papa
India
Golf

This route was followed twice at approximately 5 knots.

3.2.3 Manoeuvring Sensitivity Tests

Route 1

Charlie
Bravo
Echo
Foxtrot
Juliet
India
Papa
Quebec
Uniform

Tango
Echo Echo
Foxtrot Foxtrot
Oscar Oscar
Papa Papa

This route was followed at approximately 5 knots. The reverse route was then followed.

Route 2

This route followed several heading changes at approximately 10 knots. The times listed are from the original plan and are approximate.

Starting at point Charlie at heading 0°:

TIME Hr	Min	TURN
	0	Hdg. 0°
	5	50° P
	8	16° P
	14	41° S
	18	09° S
	23	70° P
	31	21° P
	37	104° P
	41	23° P
	47	32° P
	55	60° P
	58	58° S
1	4	58° S
1	10	24° S
1	13	15° P
1	21	10° S
1	26	74° S
1	32	50° S
1	36	20° S
1	41	33° P
1	45	19° S
1	52	46° P
2	00	24° S
2	06	46° S
2	10	13° S
2	18	44° S
2	22	47° P
2	28	29° S
2	31	37° P
2	36	29° P
2	40	48° S
2	46	29° S
2	50	40° P
2	56	74° P
3	00	

This route was followed once.

3.2.4 Endurance Test

The endurance test consisted of a long slow route containing significant latitude changes.

3.3 CONDUCT OF TRIAL

Installation, alignment and calibration of sensors took place between 10 and 16 August 1992.

The sea trial began on 17 August and lasted until return to Esquimalt on 25 August.

All equipment functioned normally with no catastrophic failures. Data logging on the MK-29 was continuous with a 'system reset' performed every 24 hours using STARFIX/DGPS as the reset position reference. One hundred and sixty-nine MK-29 data files were recorded.

LTN-90 data logging was suspended twice during the trial for several hours each time to permit downloading of data to backup floppy disks since the system disk drive was incapable of holding all of the data for the trial. One hundred and sixty-six LTN-90 data files were recorded.

MINS data was logged on 3.5-inch floppy discs. One disc failed to initialize properly and approximately 7.5 hours of data were lost. Twenty-three MINS data files were recorded.

A log book was kept in each laboratory and all significant events were entered for future reference. Sea conditions were calm to 2-metre swells for the entire duration of the trial. Upon return to CFB Esquimalt, data was logged for several hours after docking to observe any settling effects. The sensors were then unloaded from the vessel and returned to DREO. This was completed on 26 August 1992.

4. SUMMARY

DIINS Sea Trial 92-01 was successfully carried out on board CFAV Endeavour off the west coast of Vancouver Island from 17-25 August 1992. All sensors and data recording systems operated as expected providing a total of approximately 400 Mbytes of data. This data is now being analyzed and used to develop an XDM of DIINS to be trialed in late 1993.

ACKNOWLEDGEMENTS

The conduct of a sea trial involving large quantities of equipment requires the skilled capabilities of many people. In particular, the work of Lloyd Gallop in organizing the trial and Pierre Richer in preparation and installation of equipment are noteworthy. In addition, Tom Goguen of CARO Engineering developed the data recording software and provided detailed documentation.

REFERENCES

[1] J.C. McMillan, "Multisensor Integration Techniques in the DREO Marine Integrated Navigation System (MINS)", DREO Report No. 986, August 1988.

[2] J.C. McMillan, "MINS-BII: A Marine Integrated Navigation System", in Navigation, Land, Sea, Air & Space, M. Kayton editor, IEEE Press (New York), pp.161-171, 1990.

[3] C.A. Maskell, "System Analysis and Sea-Trial Results of the DREO Marine Integrated Navigation System (MINS)", DREO Report No. 943, Feb 1986.

[4] J.C. McMillan, J.S. Bird, D.A.G. Arden, "An Hierarchic Alliance of Filters for Fault Tolerant Navigation Using Two Inertial Systems with Aiding Sensors", AGARD Conference Proceedings 525 on Integrated and Multi-Function Navigation, Ottawa, May 1992.

[5] "MK-29 Mod 3 Digital Interface with Canadian Reset Message", Sperry Document #EB1897641.

[6] "MK-29 Mod 1S/Mod 3 Serial Digital Interface Operation and Service Manual Supplement", Sperry Document #1976622.

[7] "The Sperry MK-29 Data Logging System, An Operational Guide", CARO Engineering Limited Contractor Document, 4 Aug 1992

[8] "Technical Description of LTN-90 Inertial Reference System", Litton Aero Products Document #502006, January 1982.

[9] "The Litton LTN-90 Data Logging System, An Operational Guide", CARO Engineering Limited Contractor Document, 4 Aug 1992.

[10] "Multi Channel ARINC-429 Test/Simulation and Monitor Card with Error Injection", Excalibur Systems Inc., 1991.

[11] "Ashtech Geodetic Post-Processing Software (GPPS)". T.M. Ashtech Inc.

[12] "3DF Attitude Determination Installation and Receiver Operating Guide", Ashtech Document #600082, July 1992.

[13] "MK-29 Mod 3 Ship's Inertial Navigation System Operation and Service Manual", Sperry Marine Inc., 1988.

DOCUMENT CONTROL DATA

(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)

1. ORIGINATOR (the name and address of the organization preparing the document. Organizations for whom the document was prepared, e.g. Establishment sponsoring a contractor's report, or tasking agency, are entered in section 8.)

Defence Research Establishment Ottawa
Ottawa, Ontario
K1A 0Z4

2. SECURITY CLASSIFICATION (overall security classification of the document including special warning terms if applicable)

UNCLASSIFIED

3. TITLE (the complete document title as indicated on the title page. Its classification should be indicated by the appropriate abbreviation (S,C or U) in parentheses after the title.)

CONDUCT OF NAVIGATION SYSTEMS SEA TRIAL 92-01 (U)

4. AUTHORS (Last name, first name, middle initial)

VINNINS, M.

5. DATE OF PUBLICATION (month and year of publication of document)

MARCH 1993

6a. NO. OF PAGES (total containing information. Include Annexes, Appendices, etc.)

31

6b. NO. OF REFS (total cited in document)

13

7. DESCRIPTIVE NOTES (the category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.

DREO Technical Note

8. SPONSORING ACTIVITY (the name of the department project office or laboratory sponsoring the research and development. Include the address.

Defence Research Establishment Ottawa, Electronics Division
Communications and Navigation Section, Ottawa, Ontario K1A OK2

9a. PROJECT OR GRANT NO. (if appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant)

041LJ

9b. CONTRACT NO. (if appropriate, the applicable number under which the document was written)

10a. ORIGINATOR'S DOCUMENT NUMBER (the official document number by which the document is identified by the originating activity. This number must be unique to this document.)

DREO Technical Note 93-8

10b. OTHER DOCUMENT NOS. (Any other numbers which may be assigned this document either by the originator or by the sponsor)

11. DOCUMENT AVAILABILITY (any limitations on further dissemination of the document, other than those imposed by security classification)

(X) Unlimited distribution
( ) Distribution limited to defence departments and defence contractors; further distribution only as approved
( ) Distribution limited to defence departments and Canadian defence contractors; further distribution only as approved
( ) Distribution limited to government departments and agencies; further distribution only as approved
( ) Distribution limited to defence departments; further distribution only as approved
( ) Other (please specify):

12. DOCUMENT ANNOUNCEMENT (any limitation to the bibliographic announcement of this document. This will normally correspond to the Document Availability (11). however, where further distribution (beyond the audience specified in 11) is possible, a wider announcement audience may be selected.)

Unlimited Announcement

13. ABSTRACT (a brief and factual summary of the document. It may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall begin with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (S), (C), or (U). It is not necessary to include here abstracts in both official languages unless the text is bilingual).

A sea trial was held 9-26 August 1992 on board CFAV Endeavour out of CFB Esquimalt to record data from various navigation sensors to support ongoing development of an experimental development model (XDM) of DIINS (Dual Inertial Integrated Navigation System) and to evaluate the performance of MINS (Marine Integrated Navigation System) and of an Ashtech 3DF GPS (Global Position System) receiver. This report describes the preparation, installation and conduct of this trial.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus. e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus-identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

Navigation
Sea Trial
MINS
DIINS
GPS
GPS attitude determination